[Proc. Roy. Soc. Victoria, 38 (N.S.), 1926.]

Art. XVII.—*The Annual Variation in the Velocity of Cirrus Cloud over Melbourne.*

By E. KIDSON, O.B.E., D.Sc., F.Inst.P.

[Read 15th October, 1925.]

To determine the direction and velocity of movement of a cloud from surface observations, it is necessary to know both the height of the cloud and its rate and direction of angular movement. To determine the cloud height directly at each observation would be beyond the resources of meteorological institutions. The mean heights of the different types of cloud have, however, been determined from extended series of observations at a number of stations. At Melbourne such a series was obtained by photographic methods (1). With a knowledge of these mean heights, an experienced observer is usually able to make a fairly accurate estimate of the height of any particular cloud.

The angular motion of a cloud is determined by some form of nephoscope, and for the great majority of the Melbourne observations the type used was Besson's Comb Nephoscope. During the last two years, however, a Pilot Balloon theodolite has been substituted. This instrument has proved very satisfactory. A cloud point is observed in precisely the same manner as a Pilot Balloon would be; an estimate of the height of the cloud is made and its component and resultant velocities computed. As all the necessary routine has already been developed in connection with the Pilot Balloon work, in which skill and speed are attained by long practice, the method consumes the minimum amount of time.

The altitude of Cirrus cloud shows a pronounced annual variation which was roughly determined for Melbourne by the observations already referred to (1).

For computing the nephoscope observations prior to July, 1924, the following heights, based on the above determinations, have been used:—

Month	Height km.	Month	Height km.
January	10·0	July	8.5
February	9.5	August	8.5
March	9.5	September	8.5
April	9.0	October	9.0
May	8.5	November	9.5
June	8.5	December	10.0

The height assumed for January may be too great. No photographic measurements were made in that month.

From July, 1924, to date the Pilot Balloon theodolite results, in which the height of the cloud was estimated at the time of observation, have been adopted.

Observations, though not very numerous, are available for the period July, 1897, to June, 1901, when the photographs were being taken at the Melbourne Observatory (1), and for these, of course, the height was determined directly. From September, 1905, onwards, except for a break from January, 1908, to April, 1909, the observations have been fairly regular, the great majority being made by Mr. E. T. Quayle.

To determine the annual variation, the west, east, south and north component velocities for each observation were tabulated for each month, and the mean for all observations computed. Where several observations were made on the same day, the mean for that day only was tabulated in order that the day in question should not be given too much weight. This was desirable, since although there is probably a diurnal variation in Cirrus movements, and, at times, large changes take place with remarkable rapidity, certain characteristics are usually maintained for some days. The minimum number of observations thus rendered available for any month is 122, so that the resulting mean velocities should be fairly reliable. From the methods used the results must necessarily be rough, especially as the number of days on which Cirrus is observed in any month varies within wide limits. It is useless, therefore, to strive for great consistency or refinement in their treatment, provided systematic errors are eliminated so far as possible. It is anticipated, nevertheless, that the final error is unlikely to exceed 10 per cent. of the resultant velocity.

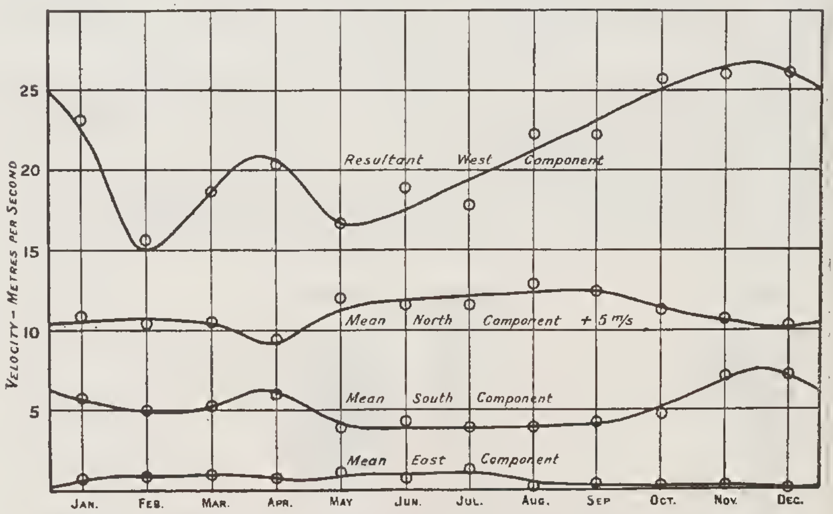

Fig. 1.—Velocity of Cirrus Cloud from Nephoscope Observations at Melbourne.

In Fig. 1 the velocities are given in metres per second. The actual values for each month are indicated by the small circles. The curves were drawn so as to indicate what seemed from a detailed consideration to be the most reliable interpretation of the results. The uppermost curve gives the resultant westerly component, i.e., the resultant eastward motion of the air. The resultant was plotted in this instance because it is, perhaps, the most interesting and important of the observed quantities, and, in any case, the easterly component is never large. The eastward movement is the most marked characteristic of the atmosphere in our latitudes, at least up to the Cirrus level, and the westerly component correspondingly predominates in the Cirrus movement. The mean resultant westerly velocity for the year is 21·1 metres per second. A particle moving with this velocity in the latitude of Melbourne would encircle the earth in about 16·5 days.

The values for the mean northerly (southward moving) component given in the second curve have all been increased by 5 m/s to render the diagram clearer.

In the westerly component, the February minimum seems to be abnormally low. Otherwise the four curves are remarkably consistent, one with another, and of a form not uncommonly met with in quantities so intimately related with the general circulation. The curve for the south component is the most typical. The maximum velocity is reached early in December, while a subsidiary maximum occurs in April. The principal minimum is a very flat one, covering the winter months. It is probable that were sufficient observations available the annual variation in the height of the Cirrus would be found to be very closely similar. Even the existing observations prove a considerable resemblance. Similar remarks apply to the mean eastward velocity of anticyclones over the whole of the Australian region. It is interesting to note, however, that the Cirrus velocity is about two and a-half times that of the anticyclones. The anticyclones—that is, the pressure systems of our weather charts, do not, therefore, move with the currents at Cirrus level.

Other quantities showing relationships in their annual variation with that of Cirrus velocities are the pressure at McMurdo Sound and at Batavia respectively, and the height of the stratosphere. At McMurdo Sound (Lat. 78°S.), where the pressure variation appears to be controlled by the Polar Cyclone, the principal maximum is in December, a secondary one in April, and the lowest minimum at the latter end of winter. At Batavia (6·2°S.) the variation is reversed, the minima being in December and April. In the northern hemisphere the height of the stratosphere has maxima in the corresponding months, June and October. There are not sufficient observations to give a reliable annual variation curve for the height of the stratosphere at any station in the Southern Hemisphere, but Batavia observations indicate maxima in January and May, giving a lag of one month on the other quantities. The proper interpretation of these relationships would bring to light facts of the greatest importance concerning the general circulation of the atmosphere.

The most striking feature of the curves is the opposition between the variations of the northerly and southerly components, the curves being almost mirror images of each other. This signifies that the total motion in the north to south or the reverse direction, or the arithmetical sum of the two components, is nearly constant. It is not, however, quite constant, but has a slight annual variation similar to that of the westerly component. The westerly component is about twenty times as large as the easterly, but, proportionally, they show just the same opposition as do the northerly and southerly components. In this case, also, therefore, the total motion, regardless of direction, has a smaller variation than that of the components.

Generally speaking, the south and west components have a similar annual variation which is the reverse of that of the north and east. The suggested explanation of this interesting relationship is that air with a strong northerly or easterly component in its motion has a different origin from that with a strong westerly or southerly component, moves in a distinct mass, and is separated from it by rather marked surfaces of discontinuity. The northerly and easterly currents presumably correspond with the "Equatorial Air" of the Norwegian "Polar Front" theory and the westerlies and southerlies with the "Polar Air."

The depth of the February minimum may be produced to some extent by local influences, such as the position of Melbourne at the south-east corner of Australia, where the maximum effect of the continent on the air circulation is felt, or it may be due partially to accidental causes, the effects of which will be smoothed out when a larger number of years' results are available. The fact that the northerly and easterly components are smaller in February than the run of the curves would lead one to expect, lends support to the latter suggestion.

The curve for the westerly component differs from that of the southerly, in addition to the depth of the February minimum, in that, instead of a flat minimum during the winter months, there is a continuous increase in velocity from June to December. This type of variation is mirrored in the easterly component, while the southerly type is reversed in the flat winter maximum of the northerly component.

From the above we see that there are two aspects of the annual variation of Cirrus movement. First we have the general mass of air moving with a westerly velocity which varies in the manner shown in the top curve of the figure. With this the southerly component appears to merge naturally. In fact, the westerly velocity may be the result of the continuous degradation of the energy of the southerly winds. On the other hand, the invasion of a strong northerly or easterly wind brings about a reduction in the general velocity. This is in accordance with our experience, easterly winds particularly producing intense anticyclones and general stagnation. Over Melbourne the northerly component is rather stronger on the average than the southerly. The northerlies probably lose their identity in cooling and mixing processes, chiefly in Antarctic and Subantarctic latitudes.

The low velocities in February and in winter are connected no doubt with the oscillation in the general circulation following the seasonal movements of the sun. The best index of this in the Australian region is, perhaps, the latitude of the moving anticyclones. The latter reach their southern limit everywhere in February. The month in which the most northward latitude is reached, however, varies from place to place; in the centre of the continent it is in June, while in the Tasman Sea it is as late as September, hence the flatness of the winter minimum. The low velocities occur in the intervals between the invasion of the temperate westerlies by the tropical easterlies and vice versa.

The variations in the velocity components bear, in most respects, a close resemblance to those in the frequency of occurrence of Cirrus from the corresponding directions as determined by E. T. Quayle (3). That is, the frequency of occurrence increases with increase of velocity. Though there is a falling off in frequency in February and March, however, the February minimum is not nearly so marked as in the velocity. The northerly component is relatively more important when velocities are considered than as derived from observations of direction only. The present results, therefore, give a more northerly mean direction than that obtained by Mr. Quayle (3). From January to April inclusive, the resultant direction differs little from due west (270°), though it is, perhaps, a little south of west in April. Thereafter, there is a sudden change, the direction being approximately 10° north of west (280°) from May to August. A gradual swing follows to the most southerly direction (265°) in November or December.

The fact that the frequency of appearance of Cirrus is roughly proportional to its velocity suggests that the mean velocity of the cloud is greater than that of the air at the same level, which is somewhat unfortunate from the point of view of the interpretation of the results.

The data are not sufficient to determine the characteristic variations of Cirrus movement in seasons of different types. Such evidence as there is indicates that the motion is faster at sunspot minimum than at sunspot maximum.

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